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Biodegradation of Organic Matter and Holding of N、P during Aerobic Thermophilic Composting of Human Feces

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Abstract

Aerobic composting is a method for sanitary disposal of human feces as has been used in bio-toilet systems. As the composting method can be used at family in city to save water and to control water pollution, it would be favorable if the composting process could be controlled to improve biodegradation of organic matters and holding of N、P. In this study, batch experiments were conducted using a closed aerobic composting reactor with sawdust as the bulky matrix to simulate the condition of a bio-toilet for sanitary disposal of human feces. Attention was paid to the Biodegradation of organic matter and holding of N、P. Under a controlled condition of temperature at 60℃, moisture content at 60%, and continuous air supply, more than 70% fecal organic mattres removal was obtained while merely 17% fecal nitrogen loss without loss of P was observed in a two-week composting period. The nitrogen loss was found to occur mainly in the frst day with quick depletion of inorganic nitrogen and unchanged organic nitrogen content. The fecal NH4-N which was the main compoernent of the inorganic nitrogen (>90%) decreased quickly in the first day, gradually decreased in the following days, and finally disappeared. Thermophilic composting could be considered to keep more than 70% fecal organic matters removal, decreasing fecal nitrogen loss, keep more organic nitrogen content without loss of P in the composts for well controling water pollution of lake, waterland or wetland.

Keywords: composting reactor, human feces, aerobic thermophilic composting

Introduction

Aerobic composting has been recognized as an applicable method for sanitary disposal of human feces in a bio-toilet system [1]. It draws attention especially from regions and areas where provision of sufficient water for toilet flushing is difficult due to water shortage [2]. In order to maintain a hygienic condition for using the bio-toilet, special measures are often taken for its operation. The operational temperature for the commercial bio-toilet has thus been recommended as 50℃-60℃ through an automatically controlled heating system [3].
Many studies have so far been conducted on the characteristics of aerobic composting for sanitary disposal

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of human feces. Attentions are mainly given to the process of biodegradation in which organics and fecal nitrogen are decomposed or transformed under the action of microorganisms, and the effect of pathogen inactivation which is the most important issue from the sanitary viewpoint under thermophilic condition. A thermophilic condition ranging from 50℃ up to 65℃ have been recognized to be optimum both for obtaining the best biodegradation effect [4] and effective removal of E. coli and other pathogens [5-7]. Some studies have indicated that addition of mixtures, as bulky matrices or composting additives, is important for maintaining an aerobic condition and greatly influences the organic decomposition and nitrification process [8, 9]. The mixtures with high lignocellulose contents, such as sawdust which in most cases is less biodegradable than other additives, can decrease nitrogen loss in the composting process [10, 11]. As the composting products can be utilized as fertilizers, it would be favorable if the composting condition could be well controlled for holding fecal N and P as far as possible in the composts. In different studies using sawdust as bulky matrices for feces composting, nitrogen losses are reported in a wide range from less than 50% to as high as 94% [7, 12, 13] depending on the composting conditions. Fecal nitrogen may be categorized into three parts as initially inert one, slowly biodegradable one, and inert one reproduced by endogenous respiration of heterotrophic microorganism, and those remained in the composts are the sum of the first and the third parts [14]. However, the process of biodegradation of fecal organic matters during aerobic composting is still a topic needing detailed investigation [10, 13-16].

Our previous work on a prototype bio-toilet for sanitary disposal of human feces shows that high percent fecal organic matters could be well biodegraded in the composts under thermophilic condition [7, 17]. In order to gain understanding on the process of biodegradation of organic matters of fecal in the composting process and the characteristics of their biodegradation under an aerobic thermophilic condition, an experimental study was conducted using a specially designed device. Attention was mainly paid to the process of biodegradation of organic matters of fecal and holding of N、P in the composting process.

Materials and methods

Experimental device The experimental device used in this study is a closed composting reactor as shown in Fig. 1. The reactor chamber is a polymethyl methacrylate cylinder with inner diameter as 10 cm and height as 55 cm. An outer jacket space is provided as a water bath where hot water is circulated through a pump connecting to the thermo controlled water heater. A hand-driven shaft with agitation blades is mounted horizontally in the reactor for intermittent mixing. An air diffuser is set at the bottom of the reactor for introducing a constant air flow through the air supply unit. An exhaust pipe on top of the reactor is connected to a water cooled condensing unit where vapor is condensed and gas is led to an ammonia absorber containing sulfuric acid solution for absorbing the exhausted ammonia gas from the reactor.

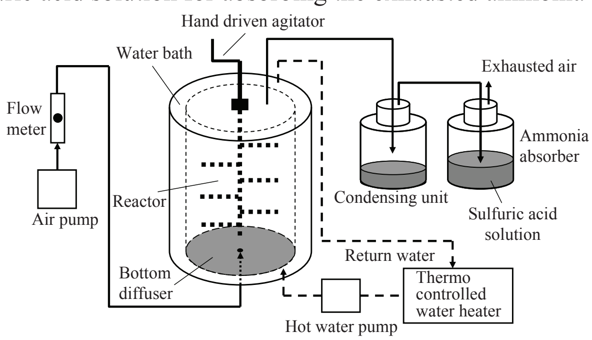


Fig.1 Diagram of the experimental composting reactor

Raw materials The bulky matrix used in this study was sawdust from a local timber processing plant. The main components of the sawdust were cellulose (about 44%), hemicellulose (about 18%) and lignin (about 35%). It was found in previous study that these lignocellulose substances were non-biodegradable and could keep a stable state after using for several months in a composting reactor [18, 19]. The human feces used in this study were collected from the university campus under the assistance of students. In order to keep the initial quality of the feces identical in different experimental runs, the collected substances were well mixed, divided into equal quantity stocks, and preserved at -20oC for later use. The physicochemical properties of the sawdust and feces are shown in Table 1 regarding their moisture content, organic solid content (S_{org}), total organic carbon (TOC), chemical oxygen demand (COD), total nitrogen content (N_{tot}) and its organic and inorganic parts (N_{org} and N_{ino}). These contents were calculated on dry solid weight basis as g/kg for either sawdust or feces.

Table 1 Physicochemical properties of the sawdust and feces used in the experiment

item	moisture content %	S_{org} g/kg	TOC g/kg	COD g/kg	N_{tot} g/kg	N_{org} g/kg	N_{ino} g/kg
sawdust	11.1	956.9	378.1	1270.3	2.10	2.10	0
feces	81.8	901.0	497.9	1671.3	68.23	55.94	12.29

For each experimental run, human feces was mixed with sawdust particles to a dry weight ratio of feces/sawdust as 1:4 following our previous experience of using sawdust as the solid matrix in the bio-toilet system [7, 11, 17]. The total wet weight of the mixture was 1 kg. As the sawdust particles were almost inert in the composting reaction, their main function was to provide void space within their porous structure for ventilation, and the dry weight ratio of 1:4 was found to be the limit condition above which the aerobic composting condition might become difficult to maintain.

Operation conditions The initial moisture content of the composting mixture, i.e. the feces and sawdust with dry weight ratio of 1:4 was adjusted to 60% using deionized water. During the composting operation, the condensed water collected in the condensing unit (Fig. 1) was sent back to the reactor daily for maintaining the moisture content. From the thermo controlled water heater, hot water with a constant temperature of 60℃ was circulated between the heater and the water both (Fig. 1) so that a constant temperature was kept in the reactor.

It was found by preliminary experiment that under the thermophilic condition at 60℃ all organic matters and nitrogen of various forms in the feces reached stable concentrations after 10 to 12 days [12]. The composting period for each experimental run in this study was set as 14 days[19].

In order to maintain a completely aerobic condition in the reactor, air flow was controlled as 0.4 $m^3min^{-1}kg^{-1}$ for feces composting in this study. Intermittent mixing of the composting mixture was provided throughout the composting process by operating the hand mixer mounted in the reactor (Fig. 1) for about 2 min in every 8 hours for keeping the mixture in a homogeneous condition following the practice of normal composting operation[8].

Sampling of composting mixture and gaseous ammonia. The composting mixture was sampled everyday during the composting process after completely mixing the mixture in the reactor. The wet weight of each sample was 10 g which took 1% of the total substance in the reactor. The daily loss of mixture by sampling was accounted in material balance calculation in this study. Each sample was immediately stored at -20℃ for analysis later.

Analytical methods.

For each sample of the composting mixture, organic matter analysis was conducted regarding COD and TOC. The COD was analyzed by a modified fast digestion-spectrophotometric method [12, 20-21] and calculated on dry solid basis. The TOC was measured directly using Shimadzu SSM-5000 with TOC-Vcph analyzer. The measured organic contents contributed by the sawdust were exempted from the final calculation of fecal COD and TOC contents on dry weight basis as g/kg.

For the analysis of nitrogen contents, liquid extraction was firstly conducted. Total nitrogen (N_{tot}) was analyzed by alkaline potassium persulfate digestion-UV spectrophotometric method[22]. Regarding inorganic nitrogen, nitrites (NO_2-N), nitrates (NO_3-N) and ammonium (NH_4-N) were analyzed by EDTA spectrophotometric method, phenoldisulphonic acid spectrophotometric method, and Nessler's reagent colorimetric method, respectively, and their summation was calculated as the total inorganic nitrogen (N_{ino}) [20]. The difference between N_{tot} and N_{ino} was calculated as organic nitrogen (N_{org}). All the fecal nitrogen contents were finally calculated on dry weight basis as g/kg.

Results and discussion

General performance of the composting reactor for fecal organic biodegradation As shown in Fig. 2, the composting reactor performed organic degradation well in the experimental period under the aerobic thermophilic condition. Taking COD content as an indicator of the fecal organic matter (the contribution of the sawdust to COD measurement was subtracted and only that contributed by feces was shown in the figure), it was almost halved in the first two days and the final removal of 73.5% was achieved after 6 days composting. The final TOC removal was also about 71.7% but its content was reduced slower and reached the final value after 6 days, indicating that the real organic content which could not be well represented by COD measurement might need longer time to decompose.

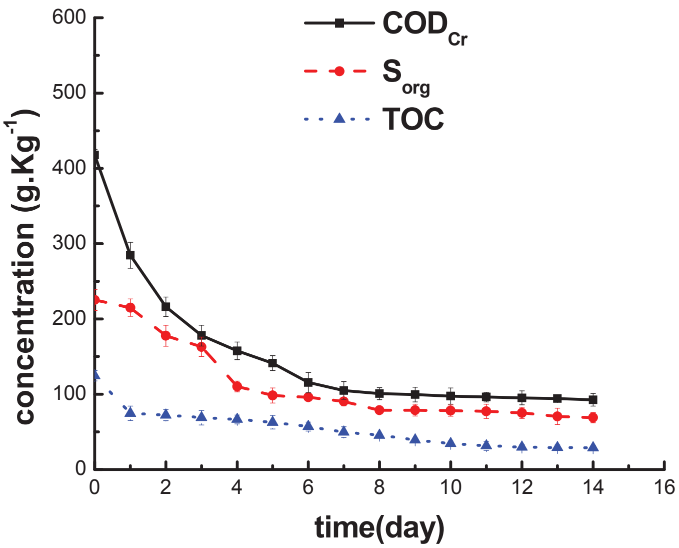
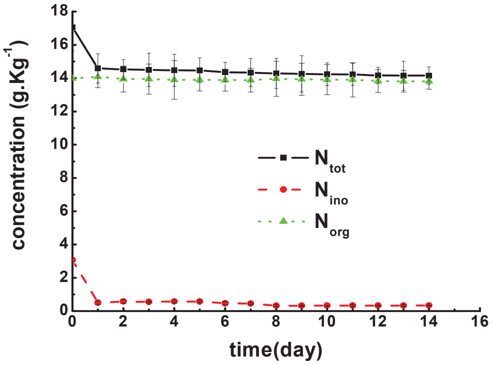
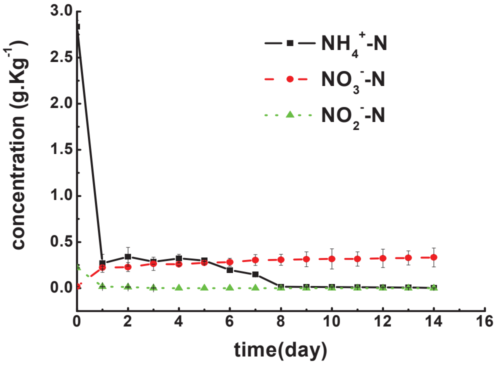


Fig. 2 Variation of fecal organic contents in the composting process

General performance of the composting reactor for fecal nitrogen biodegradation. The daily variations of N_{tot}, N_{org} and N_{ino} contents were shown in Fig. 3 a. It was noticed that N_{tot} decreased quickly in the first day of composting and then decreased gradually in the following days. The trend of variation of N_{tot} was similar to that of N_{ino} with N_{org} unchanged in the whole composting period, indicating that N_{org} was not involved in the nitrogen biodegradation process under thermophilic condition. Fig. 3 b shows the variation of the inorganic nitrogen components, i.e. NH_4-N, NO_2-N and NO_3-N in the thermophilic composting process. A quick change of concentration was seen in the first day for each component. The fecal NH_4-N which was the main component of the N_{ino} (>90%) underwent a sudden decrease in the first day, the initial NO_2-N, though its content was very low, almost disappeared after the first day, while NO_3-N increased abviously in the same time, increase of NO_3-N was equal to decrease of NO_2-N. In the following days, the NH_4-N content gradually decreased and finally diapered while NO_3-N almost kept a constant value





a b

Fig. 3 Variation of total fecal nitrogen

Change of P Fig. 4 shows the variation of P components almost kept a constant value.

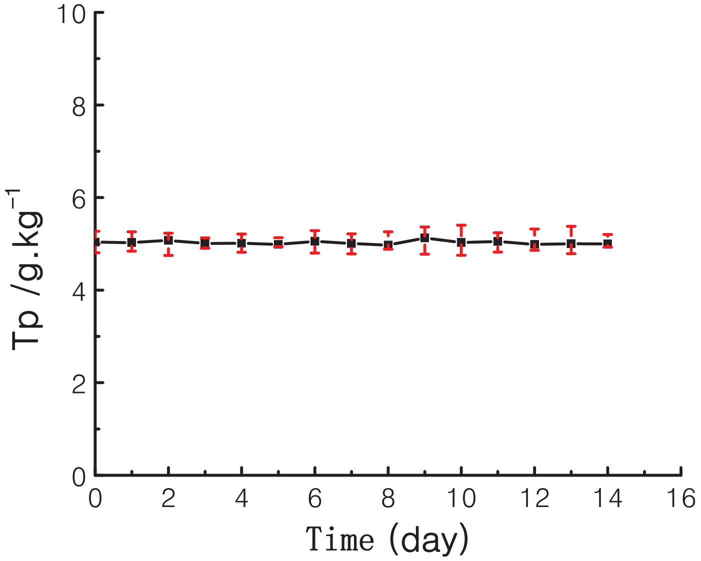


Fig.4 Variation of fecal TP in the composting process

Biodegration of organic matter in the composting reactor Only those contributed by the feces were accounted. The total nitrogen loss was 0.81 g or 17% of the initial N_{tot}. Almost all the fecal nitrogen loss was from the inorganic fecal nitrogen. The loss of fecal NH_4-N was equal to the inorganic nitrogen loss. The NO_2-N content, though with very low initial concentration, finally depleted completely while NO_3-N content was increaseand suddenly by same account of NO_2-N decreased. The organic nitrogen was unchanged. It shown that feces organic nitrogen was hinded under in aerobic thermophilic composting reactor.Of the total nitrogen contained in the feces used in this study, N_{org} took about 82% while N_{ino} was about 18% (Table 1). As shown in Figs. 3, NH_4-N which took more than 90% of the N_{ino} was quickly transformed into gaseous NH_3-N at the early stage of composting. As for the N_{org}, if it could be decomposed in the composting process, an indispensable first step would be ammonification in which the organic nitrogen could be converted into ammonium under the action of ammonifying bacteria [23]. Most ammonifying bacteria are mesophilic bacteria which are active under moderate temperature, e.g. below 40℃. From the viewpoint of bacteria growth and microbial activity, the mesophilic condition of 35℃ in this study can be considered as a suitable condition for the mesophilic ammonifying bacteria to grow or to be active. It can thus be assumed that ammonification may have been existed under the mesophilic condition due to ammonifying bacteria activity. As a result, the organic nitrogen substances in the feces were biodegradated during composting. Therefore mesophilic composting can be considered as a method to decreased the nitrogen holding property of the composts[24].

Conclusions

Under a controlled condition of temperature at 60℃, moisture content at 60%, and continuous air supply, more than 70% fecal organic biodegradation was obtained, while fecal organic nitrogen was almost unchanged. it was found that the amount of N_{tot} reduced in the first day was exactly contributed by the loss of NH_4-N which took more than 90% of the N_{ino} in the same period. It showed that ammonification may have been hined due to ammonifying bacteria lack of activity under the thermophilic condition. The fecal NO_2-N, though its initial content was very low, almost disappeared in the composting process while NO_3-N increased by the same amount. It indicated that nitrification may have been hined under the thermophilic condition due to nitrification bacteria lack of activity. As a result, the organic nitrogen substances in the feces were not almostly biodegradated during composting. The organic nitrogen that took about 82% of the fecal nitrogen kept in the composts and was thus well held in the composts. Under the thermophilic temperature of 60℃, ammonification and nitrification would have been hinded due to the unfavorable condition for the action of mesophilic ammonifying and nitrification bacteria in the reactor. Thermophilic composting could be considered to keep more organic nitrogen content whihout loss of P in the composts for controlling water pollution to lake, waterland and wetland.

Acknowledgement

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